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Considerations Applicable to an Arctic Observing System for SEARCH

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Understanding changes in the mass balance of the Arctic pack ice is a key component of the Study for Environmental Arctic Change (SEARCH), and the surface energy budget (SEB) determines the mass balance of a particular floe. A simple definition of the SEB is:

$$F_{\text{tot}} = Q^* - H_s - H_l + C, \quad (1)$$

where F_{tot} is the total energy flux into the surface slab, Q^* the net radiative flux, H_s the turbulent sensible heat flux, H_l the turbulent latent heat flux, and C the conductive flux. To understand the causes for the changes in the mass balance, each of the components of the SEB needs to be monitored in addition to the mass balance itself. The following questions are important for deciding on how to monitor the SEB: 1) what are the major contributors to changes in F_{tot} , 2) how accurately do we need to know each term, and 3) how accurately can we measure each term with a) surface measurements and b) satellite measurements? Some of the analyses from SHEBA (Persson et al 2002) and satellite studies by Key et al (1997) and others can be used to try to answer these questions.

The SHEBA measurements show that F_{tot} can undergo changes of 60 Wm^{-2} or greater in a matter of a few hours, and that each of the terms on the right-hand-side (rhs) of (1) can have similar variations. These rapid changes can happen during both winter and summer, and are often associated with synoptic or mesoscale atmospheric disturbances that produce clouds, wind, and precipitation. This frequent and large variability of all terms suggests that the measurements of the terms should be made greater than once per day, and that none of the terms can be ignored. However, dependencies between the terms may make their estimation easier. For instance, wintertime clouds (clear skies) generally produce near-zero (-40 Wm^{-2}) Q^* , small positive (large negative) H_s , and small (large) positive C . Studies of the SHEBA data set should explore these dependencies further and how they can be utilized in making satellite estimates of the terms.

The mass balance and SEB measurements at SHEBA can be used to address questions 2) and 3). The SHEBA surface ablation of 0.88 m ice equivalent implies an annual mean F_{tot} of $+8.4 \text{ Wm}^{-2}$. Considering the uncertainties in the measurements and in crucial parameters such as the thermal conductivity of snow, the observed annual mean F_{tot} was in the range $4.0\text{-}11.0 \text{ Wm}^{-2}$. Further consideration of the surface viewed by the radiometers and the best estimate of the biases, the best estimate for the observed F_{tot} was 8.2 Wm^{-2} , remarkably close to that implied by the surface ablation. A balance between the surface ablation and bottom accretion would have required a surface ablation of only 0.53 m ice equivalent, implying an equilibrium annual mean F_{tot} of $+5.1 \text{ Wm}^{-2}$. Hence, even in this case of significant mass loss, the accuracy of the annual average F_{tot} needs to be better than 3.1 Wm^{-2} in order to discriminate between the actual conditions and the equilibrium conditions. The SHEBA data is only able to make this discrimination when the arguments for determining the "best estimate" are invoked. Equilibrium

estimates using two model studies suggest that the required accuracy may be even more stringent than this simple calculation.

Extending the uncertainty estimates of Key et al (1997) to the annual time scale, the uncertainty in satellite estimates of Q^* is $1.4\text{--}2.9\text{ Wm}^{-2}$, of comparable magnitude to the required accuracy in F_{tot} to discriminate conditions of significant mass loss. However, this satellite estimate assumes no biases in the satellite estimation technique, which Key et al show is not a good assumption. Furthermore, these estimates do not consider estimating H_s , H_l , and C from satellites. Therefore, though satellite estimates of the SEB will be crucial for showing the spatial variation of the SEB terms, a handful of surface stations measuring the complete SEB and mass balance on the pack ice will be required to provide calibration of the satellite measurements and help remove biases in the satellite techniques. Even with the surface stations, clear discrimination of the causes of mass balance changes is not guaranteed, as the SHEBA measurements suggest.

REFERENCES

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